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(August 10, 1987)

PALAEOECOLOGY OF THE UPPER CRETACEOUS JUDITH RIVER FORMATION AT DINOSAUR PROVINCIAL PARK, ALBERTA, CANADA

Edited by: D.A. Eberth

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FOURTH MESOZOIC TERRESTRIAL ECOSYSTEMS SYMPOSIUM
AUGUST 10-14, 1987

TYRRELL MUSEUM OF PALAEONTOLOGY
DRUMHELLER, ALBERTA

FIELD TRIP GUIDEBOOK
TRIP A

PALAEOECOLOGY OF UPPER CRETACEOUS JUDITH RIVER FORMATION AT DINOSAUR PROVINCIAL PARK, ALBERTA, CANADA

EDITED by D.A. EBERTH

90-06666/

FIELD TRIP ITINERARY

AUGUST 10, 1987

8:00 am		Leave parking lot of Drumheller Inn
10:15	STOP #1	**Overlook at Dinosaur Provincial Park:** Greeting and introduction.
10:30	STOP #2	**Unionid Locality L1203:** Unionid-dominated mollusc assemblage and escape structures.
11:40	STOP #3	**Juvenile Corythosaurus Quarry:** Dinosaur project at Dinosaur Provincial Park.
12:15 pm	STOP #4	**Centrosaurus Bonebed:** Lunch, dinosaur taphonomy
1:45	STOP #5	**Bonebed 31:** Microvertebrate project, pisidiid-dominated molluscan assemblage.
2:40	STOP #6	**Small Theropod Quarry:** "Cathedral" sedimentology, altered volcanic ash.
3:40	STOP #7	**West "Cathedral" Butte:** Inclined Heterolithic Stratification (IHS) (TIME ALLOWING).
4:10	STOP #8	**Display House #4:** In-situ dinosaur display (TIME ALLOWING).
4:45	STOP #9	**Field Station of Tyrrell Museum of Palaeontology:** Tour of displays.
5:30		FIELD TRIP COMPLETED
6:30		**Steak-Pit at Patricia Hotel:** Western-style supper.
8:00		Supper finished. Begin drive back to Drumheller.
10:00		Arrive at Drumheller Inn.

FOREWORD

This field trip has been organized to expose the participants to as full a range of current and past palaeoecological research in Dinosaur Provincial Park as possible within a one day time limit (including a dinner stop at the Patricia Hotel's Steak-Pit — a must for any palaeoecologist). Because time for this field trip is limited, the guidebook organization reflects the sequence of stops rather than major research topics (an approach that would have demanded more time in the field). However, those participants who desire a more detailed and topic-specific reference for the palaeontology and geology of Dinosaur Provincial Park may wish to purchase a copy of the 1987 GAC Field Trip Guidebook (Koster and others, 1987) from the field trip leaders for $15.00. Copies will be available throughout the field trip and during the remainder of the conference.

The field trip comprises 9 stops including a visit to the new Field Station of the Tyrrell Museum of Palaeontology — a display, research, and resource facility situated in the Park. There are 7 field trip leaders and a variety of topics will be discussed at each stop. The guidebook does not attempt to cover these topics in detail but rather provides a brief outline of the topics and an integrated summary for each stop. We must stress that much of what will be seen and discussed during the field trip represents research that is in varying stages of completion. Within this context we hope to generate enthusiastic and productive discussions during and between stops and we heartily encourage your participation.

For your own safety please be aware of and avoid the prickly pear cactus.

Beverages will be available throughout the trip; if it is a hot day you may wish to carry at least one juice pack or soda with you.

1.0 STOP #1:

THE OVERLOOK

1.1 INTRODUCTION:

Located 48 kilometers north of Brooks (Alberta), just off the Trans-Canada Highway, Dinosaur Provincial Park encompasses 75 km² of terrain characterized by sweeping prairies, cottonwood dominated river-margin habitats, and deeply incised badlands that have yielded world renowned fossil resources (Fig. 1). Bordering the Red Deer River, this unique and beautiful combination of modern and ancient resources has made the Park one of Western Canada's most popular recreation areas. Worldwide recognition was officially achieved in 1979 when Dinosaur Provincial Park was designated a UNESCO World Heritage Site joining such distinguished company as the Grand Canyon and Great Barrier Reef. The Park was also nominated in 1984 as one of the hundred best geological sites in the Rocky Mountains Section of the Geological Society of America as a part of the Decade of North American Geology project.

1.2 STRATIGRAPHY:

Dinosaur Provincial Park contains excellent badlands-style exposure of essentially flat-lying mid-Campanian (Judithian land mammal age) Judith River Formation strata (=Oldman and Foremost formations, McLean, 1971)(Fig. 2). Subsurface data indicate that the entire Judith River Formation is up to 300 m thick in the vicinity of Dinosaur Provincial Park (McLean. 1971). Good exposures along the valley walls of the Red Deer River are typically 60-100 m thick and in the eastern portion of the Park record a transgression through the paralic Lethbridge Coal Zone up into the overlying marine Bearpaw Formation (Koster, 1984). This transgressive sequence represents the terminal portion of the Clagett Cycle (McGookey, 1972; Koster and others, 1987). A regional disconformity is present near the base of the exposed section in the Park separating two clastic wedges of differing source area, composition, and depositional style (Eberth, in preparation). Preliminary analyses of radioactive ashfall components collected from claystones in the Park indicate a typical age of 75-74 m.y. for the Park sediments (see section 7.0).

1.3 SEDIMENTARY GEOLOGY:

The Judith River Formation is a channel-dominated coastal plain sequence comprising muddy to pebbly, fine- to coarse-grained multistoreyed channels, massive mudstones, ironstones, minor coals and carbonaceous shales (Koster and others, 1987). To date, virtually all of the sedimentological studies of the Judith River Formation exposures in the Park have focused on the coarse-grained members (channel deposits). Koster (1984) and Koster and others (1987) have presented evidence that the diversity of palaeochannel types seen in the Dinosaur Provincial Park exposures represents a spectrum of estuarine environments ranging from proximal, high sinuosity reaches to distal, low sinuosity reaches. Two basic "types" of palaeochannel have been described. Type I palaeochannels dominated by inclined heterolithic stratification (IHS) (Thomas and others, in press) and comprising sand-mud couplets reflect rhythmic alternating deposition of coarse-grained bedload and fine-grained suspended sediments, largely under the influence of diurnal, tidally-induced backwater effects in the upper, high sinuosity (meandering) reaches of the estuarine channels. Type II palaeochannels comprise cleaner, trough cross-bed-dominated deposits and are interpreted as having formed in the straight reaches of the lower estuarine setting (close to palaeoshore) under fluctuating, relatively high energy flow. Type I and II palaeochannels represent endpoints in a spectrum of channel types including three additional and definable intermediate types (A, B, and C).

Wood (1985), in a detailed sedimentological study of a smaller area within Dinosaur Provincial Park ("Cathedral" area; see section 7.0) has argued that fluctuating discharge was responsible for the development of IHS sand-mud couplets in Type I channels and that the Type I and II palaeochannel deposits of Koster (1984) and Koster and others (1987) comprise genetically related though spatially distinct portions of a single, freshwater, high sinuosity fluvial system, not proximal or distal portions of estuarine channels.

It is universally accepted by all researchers who have worked with the Dinosaur Provincial Park sediments that many additional site-specific studies in this area and studies of modern analogues will have to be conducted before a more complete sedimentological picture emerges.

1.4 PALAEONTOLOGY:

The palaeontological resources of Dinosaur Provincial Park are remarkably diverse and numerous. Taken together, few localities on Earth can boast of similar riches. The vertebrate assemblage alone comprises approximately 130 species. With the inclusion of plants and invertebrates, over 200 Upper Cretaceous, Judithian age species occur as fossils in the Dinosaur Provincial Park sediments (Tables 1,2,3, and 4).

At the present time over 35 species of dinosaurs are known from the Park and new discoveries continue to be made yearly (see section 4.0). Besides the spectacular dinosaur occurrences, 32 different taxa of fish, 10 taxa of amphibians, 29 taxa of non-dinosaurian reptiles, 1 bird, and 20 taxa of mammals are presently known from the Park. Many of these forms have yet to be described suggesting that basic taxonomic and systematic work will continue to be an important aspect of palaeontological research in Dinosaur Provincial Park for many years hence.

While the vertebrates certainly comprise the most numerous and dramatic component of the fossil assemblage from the Park, invertebrates, in the form of non-marine molluscs, were probably a common part of the community. Unfortunately, widespread penecontemporaneous dissolution of $CaCO_3$ appears to have been a common phenomenon and, at present, few localities are known to produce shelly invertebrates. Insects in amber are known from other Upper Cretaceous beds in southern Alberta, and one site is now known from the Judith River Formation beds just outside the Park boundary. A sample of this amber is on display in the Field Station of the Tyrrell Museum of Palaeontology, in Dinosaur Provincial Park.

Non-marine trace fossils are particularly common in exposures below the disconformity throughout Dinosaur Provincial Park and compare well with similar assemblages present in stratigraphically equivalent beds of the Judith River Formation throughout southern Alberta. These trace fossils have received little to no attention, and their study may help to delineate subtle differences in relative rates of sediment input and reworking in the Judith River Formation.

Macroplant fossils are uncommon in Dinosaur Provincial Park and are best represented by fossilized trunks that occur as allochthonous components of channel sandstones. Leaf compression fossils are rarely encountered. Macroplant fossils include members of Taxodiaceae, Cupressaceae, Metasequoia, and Cercidiphyllum (Koster and others, 1987). In contrast, the palynological assemblage comprises at least 85 taxa (Jarzen, 1982; Table 4).

1.5 TAPHONOMY:

Taphonomic studies were begun in Dinosaur Provincial Park with the pioneering work of Peter Dodson almost twenty years ago (Dodson, 1970, 1971). During the 1970's however, very little additional taphonomic work was carried out in Dinosaur Provincial Park. The current state of sedimentological, stratigraphic and palaeontological research in the Park reflecting the more recent activities of the Tyrrell Museum and researchers at the University of Calgary and University of Alberta is now enabling the exciting merger of data from the studies to produce coherent, modern taphonomic interpretations (e.g. Currie and Dodson, 1984; Wood, 1985; Visser, 1986; Koster, 1987; Wood and others, in review). Site-specific taphonomic interpretations will be the subject of many of the following stops.

2.0 STOP #2

UNIONID LOCALITY L1203

PAUL A. JOHNSTON — TYRRELL MUSEUM OF PALAEONTOLOGY

Locality L1203 forms part of a ribbon-shaped channel lithosome approximately 250 m wide and up to 2.5 meters thick trending NE/SW that can be traced discontinuously throughout the core area of the Park. The channel lies beneath a regionally extensive disconformable contact with uppermost Judith River sediments and is conspicuous because of numerous local ironstone beds and lenses, and an abundance of iron compounds that impart to the lithosome an orange/yellow to buff color as it weathers. The dominant lithofacies in this channel deposit is low-angle inclined bedding, here interpreted as lateral accretion surfaces. Large- to small-scale trough cross-beds are also locally abundant. Of particular interest is the occurrence of a unionid-dominated mollusc assemblage associated with the up-dip portions of low-angle, inclined bedding surfaces and near the natural channel margin herein referred to as locality L1203.

Although abundant at several sites, non-marine molluscs are, on the whole, a relatively rare component of the thanatocenose of Dinosaur Provincial Park. Two discrete mollusc assemblages have been recognized including unionid-dominated and pisidiid-dominated assemblages. Locality L1203 is typical of mollusc assemblages in Dinosaur Provincial Park that are dominated by unionid bivalves. The large, heavy-shelled unionid Fusconaia? danae , (Meek and Hayden) is most common with the smaller, thin-shelled, edentulous bivalve, Anodonta propatoris (White) only occasionally encountered. Thin lag deposits at this site may contain pulmonate and prosobranch gastropods and rare pisidiid bivalves.

Living unionids lack siphons and consequently are shallow burrowers with about a half to a third of the shell exposed above the sediment/water interface. Under unidirectional flow regimes, unionids show a preferred orientation with the sagittal plane of the shell parallel to current flow and the exhalent area of the shell margin on the downstream side of the inhalent area to avoid recycling of expended water and fecal material. The long axis of the shell dips down stream. By analogy, a similar life mode is inferred for F.? danae and A. propatoris. Living unionids typically inhabit well-oxygenated, shallow, calcium-rich, permanent, lotic (flowing-water-environments that are seasonally warm and have a pH greater than 7.

Unionid-dominated mollusc asssemblages in Dinosaur Provincial Park are commonly associated with unusual, bulbous, sedimentary structures that are here interpreted as domichnia (dwelling structures) of unionid bivalves. The domichnia are especially well developed at Locality L1203 where they protrude from the underside of a shelving sandstone in densities up to 200 per square metere. The ovoid outline of the domichnia corresponds closely to the cross-sectional outline of associated shells of E.? danae. The domichnia tend to be aligned and, from analogy with modern unionids, the narrow end of the domichnia probably faced upstream relative to inferred palaeocurrent flow.

Vertical faces of the shelving sand reveal poorly defined vertical shafts that are continuous with the domichnia. The shafts are filled with meniscate laminae and are ovoid in cross-section. Comparisons with similar structures described from Palaeozoic and recent sediments indicate the shafts are fugichnia (escape-structures) generated by upward burrowing of bivalves during periods of rapid sedimentation. The prominent ridge or (ridges) on the long axis of the domichnia noted above, probably represents the initial thrust mark (or marks) of the foot at the onset of upward escape.

At some localities (eg. L1203) abundant shells occur in the beds immediately above the shelving sand or on the upper surface of the shelving sand. In these instances the shells are almost invariably articulated with the hinge undermost and the valves gaping (see TMP 86.229.1 on display in the Field Station). These observations suggest that the bivalves expired after their upward escape, perhaps from a drop in water level and consequent subaerial exposure. The shells were subsequently buried before disintegration of the ligament tissue that unites the valves.

3.0 STOP #3

JUVENILE CORYTHOSAURUS QUARRY — THE DINOSAUR PROGRAM

PHILIP J. CURRIE AND EMLYN H. KOSTER— TYRRELL MUSEUM OF PALAEONTOLOGY

Dinosaur Provincial Park has long been renowned as one of the world's major sources of Upper Cretaceous dinosaur specimens (Table 1). More than three hundred significant finds have been made, and dinosaurs from this region are on display in more than thirty institutions throughout the world. The majority of these specimens were collected between 1912 and 1925, the period of the so-called "Great Canadian Dinosaur Rush", after which collecting activities were curtailed. Since 1978, however, there has been steady increase in collecting and research in Dinosaur Provincial Park, primarily by the Tyrrell Museum of Palaeontology, with assistance from scientists from the National Museum of Natural Sciences (Ottawa), University of Pennsylvania, University of Calgary and the Alberta Research Council. Correlations with other Judithian sites in Alberta and Montana is being refined as detailed work on the stratigraphy, depositional environments and faunal and floral assemblages increases our understanding of the ancient ecosystems (Dodson, 1983).

In addition to scientists, a large crew of Tyrrell Museum technicians and volunteers work in Dinosaur Provincial Park every summer. They are divided into smaller teams who either prospect and record data on new fossil resources, excavate significant specimens, or continue a long-term excavation program at the Centrosaurus bonebed (TMP BB #143; Currie, 1982).

These surveying teams retain the type of field interests of pioneer palaeontologists during the "Great Dinosaur Rush" in terms of display and research quality articulated specimens. Indeed, over the past five years superb specimens of Albertosaurus, Centrosaurus, Kritosaurus, Gryposaurus, Chasmosaurus, Corythosaurus, Lambeosaurus and Troodon (Currie, in press) have been collected. But current Tyrrell Museum practice is broader, with the following four types of dinosaur resources now being researched: 1) "quarries" (removed articulated specimens or rare smaller remains), 2) "uncollected articulated dinosaurs" (so-called UAD's — good prospects discovered, but not yet quarried), 3) "bonebeds" (bedding-plane concentrations of commonly abraded, fragmented

and disarticulated remains), and 4) "microsites" (surface concentrations of fine-sized disarticulated remains). The main purpose of all collections data is to establish population counts for palaeoecological and taphonomic interpretation.

This particular quarry (TMP quarry #11) was opened twice by parties of the Geological Survey of Canada and the Royal Ontario Museum, and produced four half-grown specimens of Corythosaurus. In the 1940's C.M. Sternberg marked this and other quarries in the Park with a brass plate set on a post. The resulting publication (Sternberg, 1950) proved to be very influential in the early stages of the "dinosaur renaissance" more than two decades later, and provided data for the first studies on dinosaur taphonomy and physiology.

4.0 STOP #4

CENTROSAURUS BONEBED

PHILIP J. CURRIE AND EMLYN H. KOSTER — TYRRELL MUSEUM OF PALAEONTOLOGY

The Centrosaurus bonebed (TMP BB #143) was discovered by Park officials in 1977, and systematic grid excavations by Tyrrell Museum personnel began two years later. After eight summers of excavations, only about 20% of the Centrosaurus bonebed has been excavated. Present estimates suggest that the total number of individuals represented in the entire bonebed may exceed three to four hundred. Covering at least 1,500 ^{2} m and spanning up to 1.5 m in an upward fining, thick palaeochannel sequence with ironstones, wood fragments and extraformational pebbles, the spatial density of bone locally reaches 60 elements/m^{2}. The long axes of most bones are oriented parallel to the horizontal and many elements show preferred current alignment. Long bone elements at lower elevations are commonly aligned transverse to flow, and some vertebrae are imbricated! The skewed size distribution averages 17.3 cm.

Between 85-95% of the identifiable material is ceratopsian, and diagnostic ceratopsian skull elements, with one exception, can be referred to Centrosaurus — hence the name of the bonebed. Based on an early sample of 525 elements (as of the 1981 field season), the composition of the remaining assemblage is 5% carnivorous dinosaur, 3.5% hadrosaur, 1.5% champsosaur, .0.5% ankylosaur, 0.5% turtle, 0.5% Myledaphus, and 2.5% mammals, lizards and other fish. By contrast, in the rest of the Park, ceratopsians comprise less than 25% of the dinosaur assemblage. Examination of other sites throughout Alberta shows that there are also monogeneric bonebeds containing Anchiceratops, Chasmosaurus, Monoclonius, Pachyrhinosaurus, and Styracosaurus. The fact that ceratopsians tend to be found in large monogeneric bonebeds suggests either that the bonebeds accumulated over a long period of time and that the animals lived in different areas or that the bonebeds formed rapidly from the mass deaths of herds. Mass deaths of herding herbivores such as Connochaetes, Rangifer, and Bison are common in the fossil record, and still occur today. Anatomically, the dinosaurian component of the bonebed comprises about 50% ribs, 20% vertebrae, 15% skull parts, 10% limbs and small numbers of foot and girdle fragments.

To date at least 70 individuals have been identified in the Centrosaurus bonebed. These range in size from small (possibly yearlings) up to very large individuals. Study of the size distribution of the specimens produces a number of results. First, the majority of animals in the bonebed are young adults. If mortality was attritional rather than catastrophic, one would expect to find the weakest individuals (juveniles and old animals) to be dominant in the death assemblage, simply because the average-sized animals would tend to be healthy and less susceptible to death. Second, there are three size ranges known from the 70 individuals recovered. Three of these are very small and five appear to be almost double this size, with no individuals between these two sizes. The remaining animals are at least 50% larger than those in the second size range.

Similar size distributions exist in the modern organisms that breed seasonally. For example, caribbean turtles sampled one month after hatching produce three size categories: small, one month old juveniles; yearlings that are twice the size of the juveniles; and adults. Most vertebrates tend to double their size within their first year of life. The following year, however, the growth rate slows and two year old animals are only about 50% larger than the yearlings. After two years, the growth rate is so slow that it is masked by individual variation. That is, a male that is two years old may be larger than a female that is three years old. By analogy, the best explanation for the size distribution pattern seen in the Centrosaurus bonebed is that:

1. Centrosaurus bred on an annual or other regular basis (it is known that there was seasonal variation in Judithian time because of growth rings found in the bones of crocodiles and champsosaurs, and in trees.)
2. All animals represented in that particular bonebed died at approximately the same time.
3. The smallest specimens represent animals that are less than a year old.

If the evidence continues to support this hypothesis as excavation continues, then other kinds of information can be obtained. For example, it will be possible to calculate the growth rate of ceratopsians for the first few years of life. This in turn could indicate something of the physiology of horned dinosaurs. Furthermore, it will be possible to see what changes take place in morphology and proportions of the skeleton as the animals grew.

It is uncertain what caused the death of the herd of Centrosaurus. Perhaps it was flood, perhaps it was drought, or it may even have been disease. However, we do know that after death, carcasses were scavenged by carnivorous dinosaurs. These carnivores lost teeth while feeding, and these are found mixed among the bones of the ceratopsians. Tooth-marked bone has been recovered from the bonebed. Carnivores also trampled on bones of the herbivores, creating green-bone fractures. It would appear that the skeletons then were exposed for a time, allowing the bones to disassociate completely as the connective tissue rotted away. After scavenging and disarticulation, the bones were hydraulically sorted and many elements were preferentially oriented relative to the flow of the water.

5.0 STOP #5

BONEBED 31

DONALD BRINKMAN, DAVID A. EBERTH AND PAUL A. JOHNSTON

TYRRELL MUSEUM OF PALAEONTOLOGY

Upper Cretaceous microvertebrate sites comprising concentrated assemblages of disarticulated skeletal elements from a variety of small to large vertebrates are important sources of palaeoecological data (Estes, 1964; Sahni, 1972). Microvertebrate sites are particularly abundant in the exposures of the Judith River Formation in Dinosaur Provincial Park. At present, over 50 sites are known. Combined palaeontological and sedimentological study of some of these sites is now underway in an attempt to assess their palaeoecological significance. Bonebed 31 was selected to exemplify microsite research because of a number of interesting features: 1) It was the first dinosaur egg shell locality to be found in Dinosaur Provincial Park and possesses a seemingly anomolous assemblage of microvertebrates relative to many other microvertebrate sites higher in section, 2) It possesses a striking example of a locally developed pisidiid-dominated mollusc assemblage and, 3) It is a beautifully preserved though uncommon example of a non-channel, fossiliferous, depositional environment.

BB 31 occurs within a 1.5 m thick fining-upward lithosome of locally contorted carbonaceous sediments that displays a crude horizontal lamination and locally developed ripple lamination. The lithosome is sheet-shaped and has been mapped over 550 m SW-NE and 250 meters NW-SE. In all directions it is erosionally truncated by channel deposits. The fossiliferous site occurs in association with iron-rich sediments and a locally concentrated deposit of disarticulated pisidiid clam valves and rare unionids. A sheet-shaped geometry, the presence of horizontally stratified sediments as well as the absence of scour and lag deposits and large-scale stratification all indicate that the lithosome was deposited in a non-channel, relatively quiet water environment. Small-scale sandstone lenses and laminae are present and together with disarticulated microvertebrate and invertebrate fossils indicate occasional high flow velocities. Numerous abrupt contacts between laminae and lenses indicate that this area was repeatedly innundated by flood waters but the fining-upward nature of the deposit, as well as the thinning-upward nature of the beds and laminae suggests that, through time, this area was abandoned (autocyclically).

The locally dense accumulation of a pisidiid-dominated mollusc assemblage is of particular interest in this deposit. The assemblage is dominated by the thin-shelled pisiddid bivalve, Sphaerium recticardinale (Meek and Hayden). Small high-spired prosobranch gastropods form a lesser component and unionid shells (invariably disarticulated) are rare. With few exceptions, the pisidiid shells are disarticulated and many are fragmentary indicating at least moderate reworking. The limited lateral extent of the shell horizons (~10 meters) in contrast to the relatively extensive nature of the lithosome indicates that the pisidiid's source bed(s) must have been very close to the environment of deposition. Inspection of the adjacent and underlying fine-grained facies have failed to yield any evidence of in-situ pisidiids, however, this is not unexpected because, to date, all known occurrences of invertebrates with aragonite shells in Dinosaur Provincial Park have been found within uncompacted ironstone beds suggesting that it is only in these early diagenetic chemical environments that the shells are protected from dissolution. Living pisidiids are shallow-burrowing suspension feeders with the respiratory margin oriented at or near the sediment/water interface. They typically inhabit ephemeral or permanent lentic (quiet-water) environments. Locally concentrated pisidiid valves suggest that intermittent floodwaters swept through a local community of pisidiid clams carrying them a short distance on the floodplain. After each flood the invertebrate community was reestablished. Over time, either flood waters became less competent carrying fewer clams (considered unlikely) or the invertebrate community disappeared from this area.

Sediment collected in large volume from Bonebed 31 has been screenwashed as part of an ongoing survey of microvertebrate assemblages. This survey has shown that a pattern of stratigraphic change in abundance of amphibians, teleosts, Myledaphus, gar and crocodile occurs throughout the exposures of the Judith River Formation in Dinosaur Provincial Park. Specifically, amphibians and teleost fish are members of an assemblage that decrease in abundance toward the top of the section, while Myledaphus, gar and crocodile are members of a group that increase in abundance toward the top of the section. Bonebed 31, being relatively low in section and having rare gar, Myledaphus and crocodile and abundant teleost and amphibians, conforms to this overall pattern.

6.0 STOP # 6

SMALL THEROPOD QUARRY

JAMES M. WOOD AND RICHARD G. THOMAS — UNIVERSITY OF CALGARY

DAVID A. EBERTH AND PHILIP J. CURRIE — TYRRELL MUSEUM OF PALAEONTOLOGY

In 1980, the partial skeleton of a small theropod was discovered at this site. The specimen showed that Chirostenotes and "Macrophalangia" are congeneric, and suggests that Chirostenotes is a caenagnathid. The small theropod quarry area (TMP Quarry # 145) offers an opportunity to discuss an alternative explanation for the origin of the different channel types from that presented at the onset of this field trip (section 1.3, Overlook Stop). The locality also possesses a spectacular example of an altered volcanic ash deposit that has now produced the first radiometric dates for the Dinosaur Provincial Park sediments.

Well-exposed sections through a 50 m thickness of Judith River Formation coastal plain strata can be viewed from the extensive, dissected, shale plateau above of the small theropod quarry (TMP Quarry #145) 100 m east of the "Cathedral" — a prominent mesa. As illustrated in Figure 3, the "Cathedral" area sequence has been divided into six erosionally-based, 8-20 m thick, coarse-to-fine rhythms (Wood, 1985). Four main lithofacies comprise these rhythms: 1) trough cross-bedded sandstone (TX), 2) large-scale inclined heterolithic strata (IHS; sensu Thomas et al., in press), 3) sandstone with large-scale inclined bedding (IBS), and 4) shale (SH). Trough cross-bed set axes within individual rhythms' coarse members indicate unidirectional palaeoflow sub-parallel to the strike of associated IHS or IBS bedding planes (Wood, 1985).

IHS and IBS units are interpreted as products of point-bar lateral accretion within meandering, freshwater-dominated coastal plain rivers. TX sequences are recognised as being genetically related to overlying IHS or IBS units and formed as channel bottom and lower point bar deposits. This new interpretation (Wood, 1985) differs from those of previous authors (Dodson, 1971; Koster, 1983) who envisaged the coexistence of distinct braided and meandering channels (represented by TX and IHS units, respectively) on the Judith River coastal plain. It also differs significantly from Koster and Currie (1986) and Koster and others (1987) who have postulated that the Dinosaur Park palaeochannels were all estuarine in character. Palaeochannels in this area had bankfull depths of 7-

25 m and widths of 55 m to over 120 m (Wood, 1985). SH sequences represent a variety of floodplain deposits including fluviolacustrine units and immature palaeosols.

The shale unit of Rhythm 4 (SHP; Fig. 3) underlies most of the plateau. Rhythms 2, 3 and 4 are well exposed along the steep walls of the nearest coulee to the east. These rhythms are just three examples from a relatively "coarse" to "fine" continuum of point bar deposit types recognizable in the ''Cathedral'' region sequences. These lithological variants can be interpreted in terms of differences in the slope, discharge, sediment load, sinousity, etc. of their parent channels, which in turn can be related to allocyclic controls such as tectonic uplift and sea level changes (Wood, 1985). Point bar deposits of Rhythms 2 and 3 (IHS2 and IHS3; Fig. 3) comprise sandstone-mudstone couplets which display an average original (depositional) inclination of 8°. In contrast, Rhythm 4 point bar deposits (BS4) are composed almost entirely of inclined sandstone beds with an average dip of 6°. Both IHS2 and IBS4 point bar units gradationally overlie trough cross-bedded sandstone units (channel floor and lower point bar deposits). Lateral accretion beds exposed on the coulee walls dip to the north (IHS2) and south (IHS3 and IBS4), approximately perpendicular to the mean ESE-ward palaeoflow direction (determined from trough cross-beds) in this area (Wood, 1985).

To the west, Rhythms 5 and 6 (Fig. 3) crop out at upper levels of the "Cathedral". The Rhythm 6 coarse member (IHS6), comprises inclined interbeds of intraformational conglomerate and sandstone, truncates the upper portion of Rhythm 5 (represented here by TX5 only), and is seen in strike view at this locality.

The small theropod quarry occurs in association with the coarse member of Rhythm #4. Deep (metre-scale) scour of pre-existing deposits at the base of the rhythm resulted from lateral migration of the meandering channel thalweg. A widespread, coarse, multigeneric bonebed (TMP BB #10) present near the base of the rhythm is a channel lag deposit. Bone condition within this deposit varies from pristine to highly abraded and reflects diverse bone provenance and transportation histories (Wood et al., in review). Trough cross-bedded sandstones (TX4), which comprise the lower 9 m of the rhythm, were deposited in channel floor and lower-to-mid point bar environments. IBS4, which gradationally overlies TX4 (Fig. 3), consists of 2 m of ripple cross-laminated sandstones exhibiting large-scale inclined bedding, and is interpreted as an upper point-bar, lateral accretion deposit. The partial small theropod specimen Chirostenotes was recovered at the level of the TX4-IBS4 transition. It presuma-

bly represents a carcass that became stranded on a point bar as flood waters receded. Incomplete preservation of this specimen probably resulted from its subaerial exposure on the bar and concomitant disarticulation due to decomposition, scavenging, and bone removal during subsequent floods (Wood et al., in review).

A white, 0.01-0.40 m thick altered volcanic ash ("Plateau Tuff" of Wood, 1985), present 0.5-2.0 m above the base of SHP (Fig.3), can be viewed at the edge of the shale plateau near the quarry stake. Altered volcanic ashes collected from Dinosaur Provincial Park during the past year are now producing the first reliable radiometric dates for the terrestrial Judithian sediments in Dinosaur Provincial Park. At least 10 stratigraphically separate altered ash beds have been located in the Park and occur from the base of the exposures up into the Lethbridge Coal Zone and Bearpaw Formation. The quality of each ash bed is highly variable and the ash beds are typically highly contorted (bioturbated ?) and laterally discontinuous. However, a few ash beds are particularly thick and comprise uncontorted thin graded laminae of biotites and other heavy minerals interlayered with thick, shaley smectite clays (bentonite). The altered ash bed that overlies the small theropod quarry is of unusually good quality and possesses one highly concentrated lamina of biotite. The ash is part of a thick mudstone sequence that caps a bench throughout this area. A brief description of the sequence is included here to indicate the vertical facies association of this bed.

METERS:

0.00-0.50 Massive sandy siltstone, low carbonaceous content; rare, thin root traces.

0.50-1.10 Abrupt contact with dark brown, shaley, clayey, sandy siltstone; moderate carbonaceous content, coalified fragments; clay content increases upward, becomes clayey siltstone in upper 10 cm

1.10-1.40 *Abrupt and irregular contact with green ash bed; High biotite contentration in lowest 8 cm. One thin lamina (< 5mm) of very highly concentrated biotite within lowest 8 cm of bed. Remainder of bed appears massive to slighlty shaley with moderate to high biotite concentration.*

1.40-1.50 Abrupt contact with dark brown, shaley, sandy to silty claystone, waxy appearance near base; moderate carbonaceous content.

1.50-1.75 Passes up into a very finely laminated silty claystone and siltstone with minor very fine ss. laminae.

1.75-1.89 Passes up into massive clayey siltstone; low carbonaceous content.

1.89-2.50+ Remainder of overlying beds appear as massive, grey-green, silty claystone; low carbonaceous content; minor root traces; forms extensive popcorn weathered surface.

Two K/Ar dates have been obtained from the bioties from the ashes. High density biotites were separated at the Tyrrell Museum by centrifuging concentrated mineral separates in a solution of sodium polytungstate adjusted to a specific gravity of just over 3.0. Analysis of K content for these heavier biotites indicates a higher percentage (6.6-6.8) than for the lower density biotites (4.6) and thus greater reliability. The dates have come in at 74.18+/- .56 my and 74.88 +/- 2.7 m.y. (A. Deino, pers. comm). The former date of 74.18 is of greater reliability on the basis of K content. These radiometric dates remain unofficial until further tests can be made to corroborate the results.

7.0 STOP #7

WEST 'CATHEDRAL' BUTTE

JAMES M. WOOD AND RICHARD G. THOMAS — UNIVERSITY OF CALGARY

Located 100 m east of the preserve road, this prominent butte west of the "Cathedral" permits detailed examination of the internal architecture of a 13 m thick, "muddy" point bar deposit (IHS2; Fig. 3). Features to note include: 1) interdigitation of TX2 (channel floor and lower point bar sediments) with IHS2 (mid-to-upper point bar sediments) near the base of the butte, 2) large-scale erosion surfaces within IHS2 formed by flood-induced scour of the point bar, 3) lateral thickness variation and discontinuity of IHS2 beds parallel to both point bar dip and strike, 4) inclined decimeter-scale thick sandstone-mudstone couplets, and 5) sub-millimeter- to millimeter-scale interlamination of sandstone and mudstone within "mudstone" beds.

8.0 STOP #8

DISPLAY HOUSE#4

Display House #4 was built to showcase a virtually complete skeleton of Corythosaurus, excavated in 1965 by Charles Hazelius Sternberg from the sandstone ridge 10 m east of the Display House. Skin impressions are preserved and the association of the specimen with large-scale trough cross-bedding as well as subtle differences in preservation between right and left sides have resulted in an interesting and educational taphonomic exhibit. The original skull has been removed to the collections section of the Tyrrell Museum of Palaeontology and a cast put in its place.

9.0 STOP# 9

FIELD STATION OF THE TYRRELL MUSEUM OF PALAEONTOLOGY

A forty-five minute stop at the new Field Station of the Tyrrell Museum of Palaeontology is included in the field trip. The Field Station, which opened May 15, 1987, is both a display and research facility whose purpose is to support research and conservation in Dinosaur Provincial Park. The facility comprises approximately 250 m^2 of display space and 500 m^2 of research, preparation, and resource space. Researchers work out of the Field Station during the summer and some specimen preparation and cataloguing can be performed prior to storage of specimens at the Tyrrell Museum. The Tyrrell Museum shares the Field Station with Visitor Services of the Alberta Department of Recreation and Parks. During the summer, Visitor Services personnel present a variety of natural history and palaeontology programs and offer guided tours of the Park and its resources.

Displays at the Field Station are organized palaeoecologically with major treatments of aquatic, terrestrial and paralic environments, and dinosaur diversity. The regional palaeogeographic framework of the Upper Cretaceous of southern Alberta is briefly explained and exhibits on the origin and natural history of the badlands round out the story.

ACKNOWLEDGEMENTS

It is a pleasure to formally acknowledge individuals and organizations that have contributed in so many different ways to the ongoing research in and around Dinosaur Provincial Park. Drs. Peter Dodson and Dale Russell have been especially helpful in all phases of the palaeontological research. Colleagues at the University of Calgary and University of Alberta, as well as the Alberta Research Council and Institute of Sedimentary and Petroleum Geology have provided important technical assistance and countless hours of constructive discussion. Field assistants deserve special credit for shouldering much of the burden of this research. The Alberta Department of Recreation and Parks graciously provided accomodations and technical assistance at Dinosaur Provincial Park.

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TABLE 1: Vertebrate faunal list of the Upper Judith River Formation at Dinosaur Provincial Park.

CHONDRICHTHYES		
Holocephali		
Chimaeriformes	Chimaeridae	Ischyodus bifurcatius
	Rhiochimaeridae	Elasmodus cf greenoughi
Elasmobianchii		
Selachii	Hybodontidae	Hybodus montanensis
		Hybodus storeii
Euselachii	Synechodontidae	Synechodus andersoni
		Synechodus striatus
	Anacoracidae	Squalicorax kaupi
	Orectolobidae	Eucrossorhinus microcuspidatus
		Cretorectolobus olsoni
	Hemiscyllidae	Chiloscyllium missouriensis
	Odontaspidae	Hypotodus grandis
		Odontaspis sangiunei
	Cretoxyrhinidae	Plicatolamma arcuata
	Pseudotriakidae	Archaeotreakis rochelleae
Rajiformis	Rhinobatidae	Protoplatyrhina renae
Batoidae	Sclerochynchidae	Ichthyrhiza cf avonicola
		Ichthyrhiza mira
	Incertae Sedis	Ptychotrygon blainensis
	Dasyatidae	Myledaphus bipartitus
OSTEISHTHYES		
Acipenseriformes	Acipenseridae	Acipenser albertensis
	Polyodontidae	Paleopsephurus sp.
Aspidorhynchiformes	Aspidorhynchidae	Belonostomus longirostris
Lepisosteiformes	Lepisosteidae	Atractosteus occidentalis
Amiiformes	Amiidae	Kindlea sp.
?Amiiformes	incertoes sedis	gen et sp unident (Holostean A)
		gen et sp unident (Holostean B)
Elopiformes	Elopidae	Paratarpon apogerontus
	Albulidae	Coriops amnicolus
?Elopiformes	Phylodontidae	Paralbula casei
Osteoglossmorpha	incertae sedis	cf. Chandlerichthyes
?Acanthopterygii	incertae sedis	Platacodon sp.
Acanthopterygii	incertae sedis	gen et sp inident
AMPHIBIA		
Salientia	Ascaphidae	Gen. et sp. nov.(Fox)
	Discoglossidae	cf. Scotiophyrne
	Pelobatidae	Eopelobates
Caudata	Scapherpetontidae	Scapherpeton tectum
		cf. Lisserpeton bairdi
	Amphiumidae	Proamphiuma sp.
	Batrachosauroididae	Opisthotriton kayi
	Sirenidae	Prodesmodon copei
Allocaudata	Albanerpetontidae	Habrosaurus dilatus
		Albanerpeton sp.

REPTILIA		
Chelonia	Baenidae	*Neurankylus eximus*
		Boremys pulchra
		Naomichelys
	Macrobaenidae	*Plesiobaena antiqua*
	Dermatemydidae	"*Clemmys*" cf. *C. bachmani*
		Adocus lineolatus
	Trionychidae	*Basilemys variolosa*
		Aspideretes foveatus
		Aspideretes alleni
	Chelydridae	Gen. et sp. indet.
Sauropterygia	Polycotylidae	Gen. et sp. indet.
Archosauromorph	Champsosauridae	*Champsosaurus natator*
Sauria	Teiidae	*Chamops*
		Leptochamops denticulatus
	Scincidae	*Sauriscus*
	Anguidae	*Pancelosaurus*
	Xenosauridae	Gen. et sp. indet.
	Necrosauridae	*Parasaniwa*
		Paraderma
	Varanidae	*Colpodontosaurus*
		Palaeosaniwa canadensis
Sauria inc. sed.		Gen. et sp. nov.(Fox)
Ophidia	Aneliidae	*Coniophis*
Crocodilia	Crocodylidae	*Leidyosuchus canadensis*
		cf. *Brachychampsa*
	Sebecosuchian	*Albertochampsa langstoni*
Pterosauria	Pterodactyloidea	Gen. et sp. indet.
		Quetzalcoatlus sp.
Saurischia	Segnosauridae	Gen. et sp. indet.
	Ornithomimidae	cf. *Erlikosaurus*
		Dromiceiomimus samueli
		Ornithomimus edmontonicus
	Troodontidae	*Struthiomimus altus*
		Troodon formosus
		(*Stenonychosaurus inequalis*)
	Dromaeosauridae	(*Pectinodon bakkeri*)
		Dromaeosaurus albertensis
	cf. Dromaeosauridae	*Saurornitholestes langstoni*
	Caenagnathidae	(*Paronychodon lacustris*)
		Caenagnathus collinsi
	cf. Caenagnathidae	*Caenagnathus sternbergi*
		Chirostenotes pergracilis
		(*Macrophalangia canadensis*)
		(*Macrophalangia elegans*)
		Elmisaurus
	Tyrannosauridae	*Albertosaurus libratus*
		Daspletosaurus torosus
		Gracile tyrannosaur
		(*Aublysodon* sp.)
		(undescribed)

Ornithischia	Hadrosauridae	Brachylophosaurus canadensis
		Gryposaurus notabilis
		Kritosaurus incurvimanus
		Prosaurolophus maximus
		Corythosaurus casuarius
		Lambeosaurus lambei
		Lambeosaurus magnicristatus
		Parasaurolophus walkeri
	Pachycephalosaurid	Gravitholus albertae
		Ornatotholus browni
		Pachycephalosaurus sp.
		Stegoceras validus
		Full Domed form, undescribed
	Nodosauridae	Panoplosaurus mirus
		Edmontonia longiceps
	Ankylosauridae	Euoplocephalus tutus
	Ceratopsidae	Anchiceratops sp.
		Centrosaurus apertus
		Chasmosaurus belli
		Chasmosaurus kaiseni
		Eoceratops canadensis
		Monoclonius lowei
		Styracosaurus albertensis
AVES		
cf. Neognathae		Gen. et sp. indet.
MAMMALIA		
Multituberculata	Neoplagiaulacidae	Cimexomys judithae
		Mesodma primaeva
	Cimolodontidae	Cimolodon electus
		Cimolodon similis
	Cimolomyidae	Cimolomys clarki
		Meniscoessus major
		Gen. et sp. indet.
Theria inc. sed.	Deltatheridiidae	cf. Deltatheroides
Marsupialia	Didelphidae	Alphadon praesagus
		Alphadon halleyi
		Alphadon, n. sp.
	Pediomyidae	Pediomys clemensi
		Pediomys, n. sp.
	Stagodontidae	Boreodon matutinus
		Eodelphis cutleri
		Eodelphis browni
Eutheria/Insectivora	Leptictoidea	Gypsonictops lewisi
	cf. Nyctitheriidae	Paranyctoides sternbergi
	Palaeoryctidae	Cimolestes sp.
		Gen. et sp.nov.(Fox)

TABLE 2: Representative non-marine molluscs of the upper Judith River Formation slightly amended from Russell (1964); higher taxonomic assignments based on Moore (1969) for bivalves and LaRocque (1953) and Hartman (1984) for gastropods.

Class Bivalvia
  Subclass Palaeoheterodonta
    Order Unionoida
      Family Unionidae
        Pleurobema? humei (Dyer)
        Rhabdotophorus senectus (White)
        Anodonta propatoris (White)
        Quadrula? primaevus (White)
        Lampsilis? consueta (Whiteaves)
        Fusconaia? danae (Meek and Hayden)
  Subclass Heterodonta
    Order Veneroida
      Family Pisidiidae
        Sphaerium recticardinale Meek and Hayden
    Order Myoida
      Family Corbulidae
        Corbula confiniensis Russell
Class Gastropoda
 Subclass Prosobranchia (gill-breathing, aquatic snails)
  Order Mesogastropoda
      Family Viviparidae
        Viviparus nidaga Dyer
      Family Hydrobiidae
        Micropyrgus higdoni (Russell)
      Family Pleuroceridae
        Lioplacodes praecursa (Dyer)
        L. judithensis (Stanton)
        Goniobasis sublaevus (Meek and Hayden)
        G. gracilenta (Meek and Hayden)
 Subclass Pulmonata (Lung-breathing snails)
  Order Basommatophora (Predominately aquatic species)
      Family Physidae
        Physa canadensis Whiteaves
  Order Stylommatophora (Terrestrial species)
      Family Polygyridae
        Polygyra venerabilis Russell
      Family Grangerellidae
        Prograngerella sperata Russell

TABLE 3: Record of megaplant fossils from the upper Judith River Formation from Bell (1965).

Artocarpus sp.
Dombeyopsis nebrascensis
Elatocladus albertaensis
Menispermites sp.
Platanus affinis
Platanus latiloda
Sequoia sp.
Vitis stantoni

TABLE 4: Record of palynomorph species form the upper Judith River Formation at Dinosaur Provincial Park with suggested botanical relationships. Listed taxa have been taken unedited from Jarzen (1982), denoted J, and Waldman and Hopkins (1970), denoted W.

BRYOPHYTA
Family Sphagnaceae
Cingutriletes clavus (J)
Stereisporites antiquasporites (J)

ANTHOCEROTOPHYTA
Family Anthocerotaceae
Foraminisporis wonthaggensis (J)

HEPATOPHYTA
Family Spaerocarpaceae
Aequitriradites ornatus (J)
A. spinulosus (J)

MICROPHYLLOPHYTA
Lycopodiales
Family Lycopodiaceae
Lycopodiumsporites sp. (W)
Retitriletes austroclavatidites (J)
R. nidus (J)

Selaginellales
Family Selaginellaceae
Acantotriletes varispinosus (J)
Heliosporites kemensis (J)
Neoraistrickia truncatus (J)

PTERIDOPHYTA
Filicales
Family Osmundaceae
Baculatisporites comaumensis (J)
Osmundacidites wellmanii (J)

Family Schizaeaceae

Cicatricosisporites hallei (J)
cf. Klukisporites sp. (W)
Lygodiosporites sp. (W)
cf. Schizaea sp. (W)

Family Gleicheniaceae

Gleicheniidites senonicus (J)
Gleicheniidites sp. (W)

Family polypodiaceae

Laevigatosporites adiscordatus (J)
L. discordatus (J)
L. druggii (J)
L. ovatus (J)
L. sp. (W)
L. sp. (W)
Polypodiisporites amplus (J)

Family Cyatteaceae/Dicksoniaceae

Cyathidites australis (J)
C. minor (J)

Insertae sedis

cf. Triplanosporites sp. (W)

CYCADOPHYTA

Cycadales

Cycadophytus nitidus (J)

Pteridospermales

Family Caytoniaceae (extinct)

Vitreisporites pallidus (J)

CONIFEROPHYTA

Conferales

Family Pinaceae

Alisporites bilateralis (J)
Cedripites cretaceus (J)
cf. Pinus sp. (W)
Pityosporites sp. (J)
Tsugaepollenites sp. (W)

Family Podocarpaceae

Parvisaccites radiatus (J)
Podocarpidites granulatus (J)

Family Phyllocladaceae

Lygistepollenites sp. (J)

Family Taxodiaceae/Cupressaceae

Taxodiaceaepollenites hiatus (J)

GNETOPHYTA

Family Ephedraceae

Equisetosporites multicostatus (J)

ANTHOPHYTA

Family Buxaceae

Erdtamanipollis procumbentiformis (J)

Family Cercidiphyllaceae

Cerdidiphyllites brevicolpatus (J)

Family Gunneraceae	
Family Liliaceae	Tricolpites reticulatus (J)
	Liliacidites mirus (J)
	L. morrinensis (J)
	L. varigatus (J)
	L. sp. (W)
Family ?Araceae	L. sp. (W)
Family Typhaceae	Arecipites sp. (W)
	Typha sp. (W)
Family Loranthaceae/Santalaceae	
	Aquilapollenites amplus (J)
	A. asper (J)
	A. attenuatus (J)
	A. calvus (J)
	A. clarireticulatus (J)
	A. pyriformis (J)
	A. quadrilobus (J)
	A. reticulatus (J)
	A. trialatus (J)
	A. tripodiformis (J)
	A. turbidus (J)
	A. sp. (W)
	Cranwellia striata (J)
	Loranthacites catteralli (J)
Family Protaeceae	Scollardia sp. (W)
	Beaupreaidites angulatus (J)
	B. occulatus (J)
Family Symplocaceae	Proteacidites thalmanii (J)
Family ?Anacardiaceae	Symplocoipollenites vestibulum (J)
Insertae sedis	Pulcheripollenites narcissus (J)
	Tricolpopollenites sp. 1 (W)
	T. sp. 2 (W)
	T. sp. 3 (W)
	T. sp. 4 (W)
	T. sp. 5 (W)
	T. sp. 6 (W)
	Tricoloporopollenites sp. 1 (W)
	T. sp. 2 (W)
	T. sp. 3 (W)
	T. sp. 4 (W)
	T. sp. 5 (W)
	T. sp. 6 (W)
	T. sp. 7 (W)

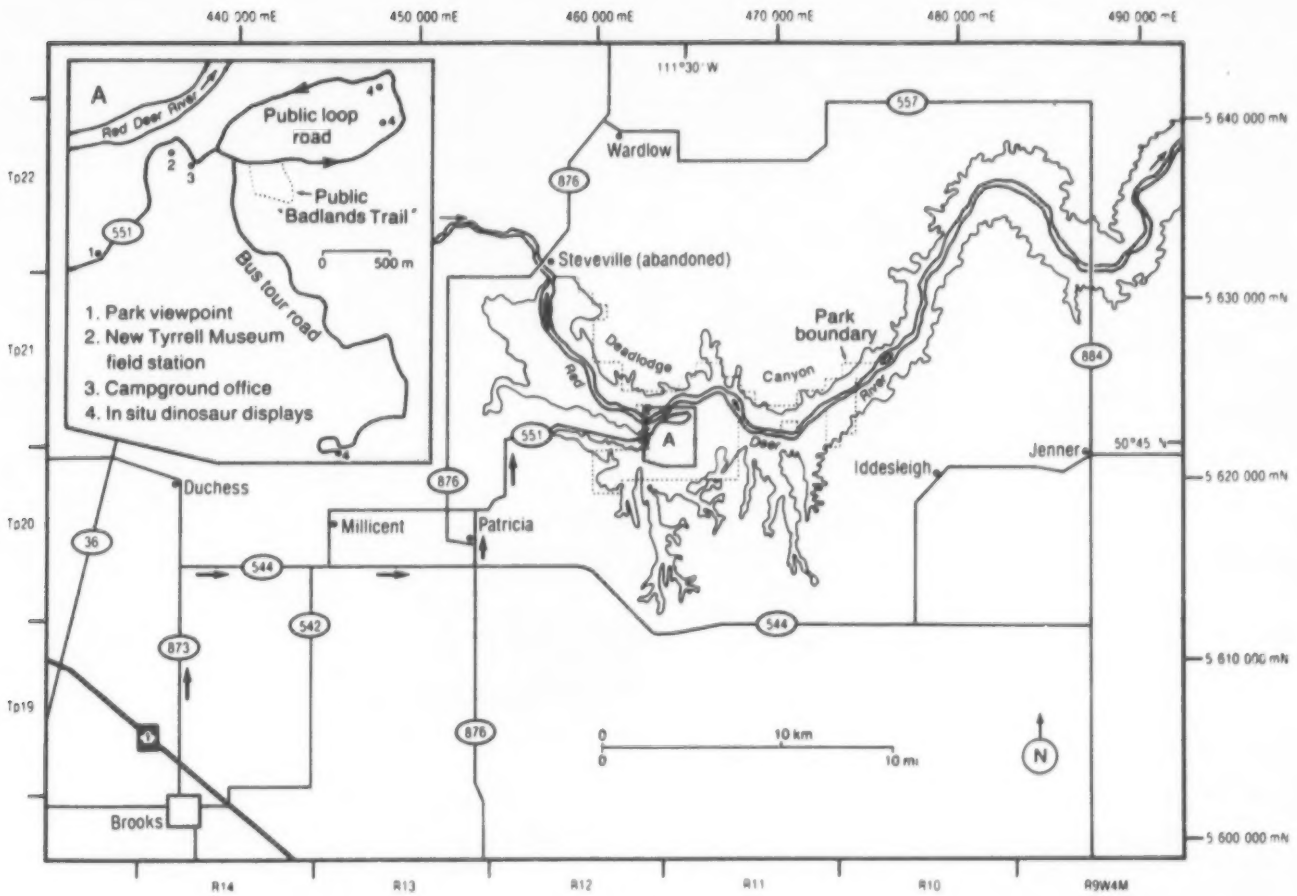

FIGURE 1. Access from Brooks on the Trans-Canada Highway to Dinosaur Provincial Park. The Inset 'A' shows the location of principal features within the Park headquarters area. The irregular line enclosing the course of the Red Deer River shows the distribution of badlands.

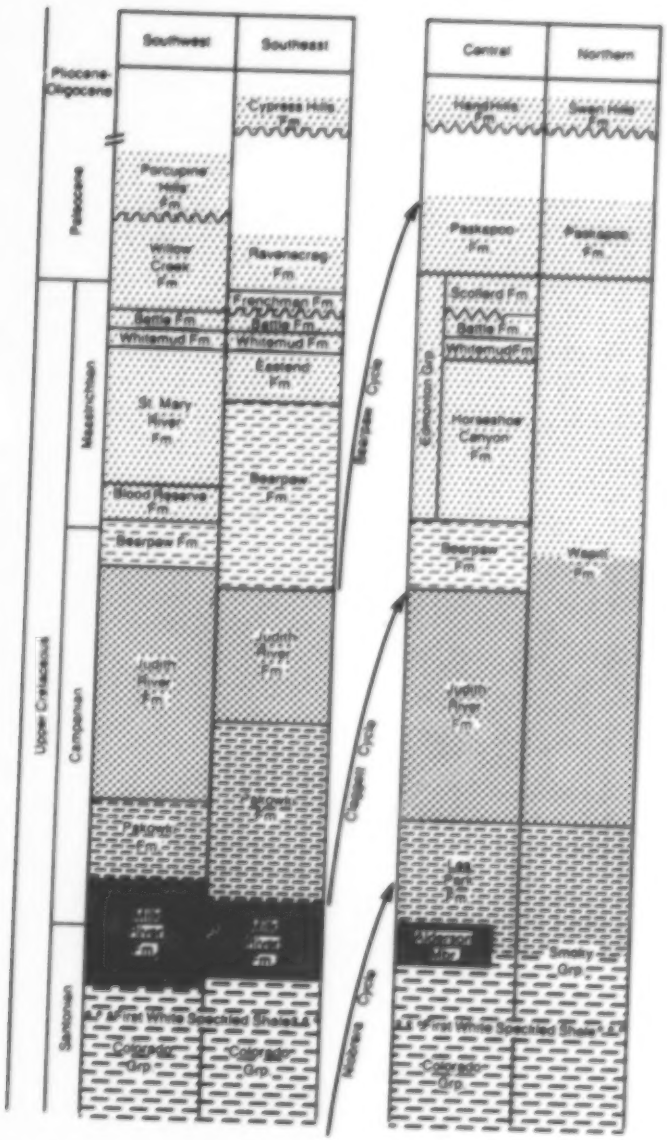

FIGURE 2. Upper Cretaceous and Tertiary stratigraphy of Alberta. Stratigraphy in Dinosaur Provincial Park and vicinity corresponds to that of Central Alberta in the figure.

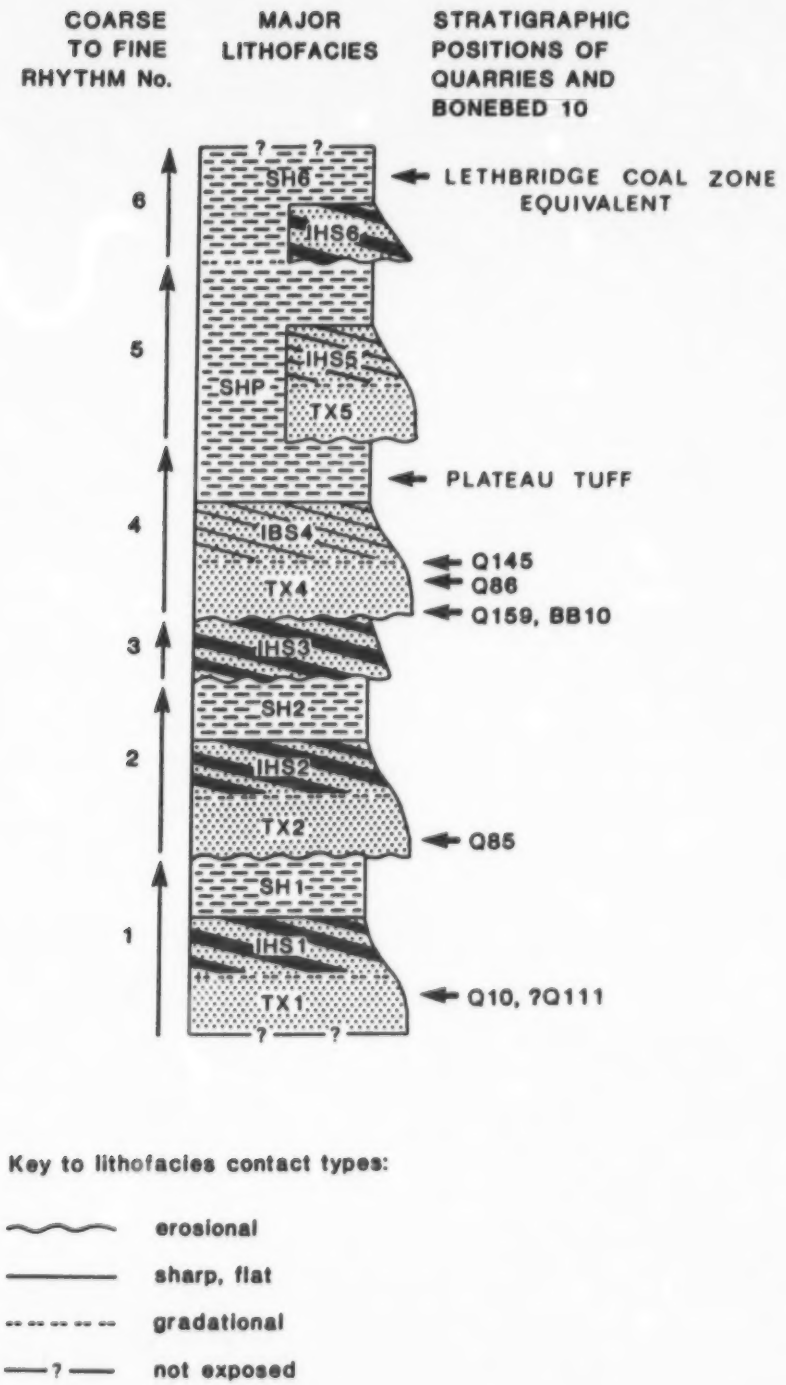

FIGURE 3. Schematic stratigraphic column (not drawn to scale) showing the major lithofacies units comprising the 60 m thick Judith River Formation section in the "Cathedral" area, plus stratigraphic positions of the Chirostenotes quarry (TMP quarry #145), TMP Bonebed #10, the Plateau Tuff, and the Lethbridge Coal Zone equivalent. Lithofacies abbreviations: TX, trough cross-bedded sandstone; IHS, inclined heterolithic strata; IBS, inclined bedded sandstone; SH, shale (from Wood and others, in review).